Estimation of Vertical Distributions of Water Vapor from Spaceborne Observations of Scattered Sunlight

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LONG-TERM GOALS

The scientific aims of this project are to investigate, develop and apply methods based solidly on scattering physics and inverse theory to estimate vertical distributions of water vapor properties from hyperspectral observations of scattered sunlight. We seek especially to advance methods for the lower troposphere, where water vapor and aerosols are concentrated and affect naval systems strongly. We are presently working on a method applicable over the sea surface.

OBJECTIVES

The current focus of the project is on physics and inverse theory for retrieval of water vapor profiles at relatively low altitudes over surfaces (from roughly 0 - 500 mB) using high spectral resolution near-IR observations of scattered sunlight, such as are expected from the NEMO/COIS sensor. We are working to quantify the fidelity and altitude ranges of inversion based on clear-air aerosol scattering, and to test alternative methods for this inversion using existing (airborne) hyperspectral observations, to the degree possible.

APPROACH

In the approximation of first-order aerosol scattering, the problem can be cast as a linear inverse problem formally similar to that of temperature sounding using microwave radiation near the oxygen absorption complex. Methods used to analyze the information content of various prospective temperature-sounding observations therefore can also be applied in this case. In particular, we use singular-value-decomposition to understand the number of profile parameters parameters for which representative (prospective) data sets can inverted. We also use Backus-Gilbert theory to understand the altitude range over which inversion is informative, as a function of the aerosol distribution with altitude. We seek to quantify the 'quality' of aerosol distribution knowledge necessary to result in water vapor profiles of useful accuracy. We are also seeking existing AVIRIS data sets that can be used to test theoretical methods observationally.

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14. ABSTRACT
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WORK COMPLETED

Our investigations have shown that the combination of viewing from the top of the atmosphere, relatively high terrestrial tempeatures, and (from a spectroscopist's point of view) modest spectral resolution of 10 nm seriously limits water vapor profiling using sunlight scattered to the sensor by underlying land surfaces. The success in profiling atmospheric trace gases using similar methods in planetary science [see, e.g., Coustenis et al., 1991] results largely from the much higher spectral resolution available with sensors on interplanetary probes and ground-based telescopes. Thus, even though the relatively high temperatures on Earth constitute an additional challenge, trace gas profiling over land should be revisited if the spectral resolution of future Earth-observing sensors is further improved. We reported on this work at the 1999 Fall Meeting of the American Geophysical Union [Winebrenner and Sylvester, 1999].

We have therefore developed a method for water-vapor profiling over ocean surfaces which is based on hyperspectral observation of sunlight scattered by aerosols at wavelengths near water vapor absorption features. The method presumes adequate independent knowledge of the vertical distribution of aerosol scattering properties -- we expect such information in practice to be acquired from some combination of air mass modeling and lidar data. We have formulated the inverse problem based on radiative transfer theory and specialized to the case of clear-air scattering with small optical depths (i.e., a first-order scattering assumption) and nadir observation angle. We have characterized the information content and range of accurate inversion possible using several combinations of near-infrared water vapor absorption features, on the basis of singular value decomposition and numerical radiative transfer modeling. We are presently formulating our results in two publications for submission later this year.

RESULTS

Two issues of first-order importance are (1) the theoretically feasible vertical resolution of retrieved water vapor profiles (which is closely coupled to the retrieval information content), for various (assumed) aerosol distributions with altitude; and (2) the relationships between uncertainties in aerosol distributions and resulting uncertainties in water vapor profile retrievals. Because some near-IR water vapor absorption features are quite sharp (as functions of wavelength), uniform aerosol distributions (in altitude) can theoretically provide finely resolved water vapor profiles. More realistic aerosol altitude distributions in the sea surface boundary layer are concentrated near the surface with scale heights roughly comparable to water vapor scale heights - resolution in such cases depends on altitude. Our numerical investigation indicates that realistic aerosol profile information, together with hyperspectral data of the quality expected from NEMO/COIS, could yield useful estimates of 3-5 parameters in a parametric representation of near-surface water vapor. In cases where several absorption features of sufficiently different depths can be utilized, the altitude range of accurate profile retrieval can extend essentially throughout the altitude range of appreciable aerosol optical depth. We continue to work on quantification of the relationship between the quality of realistic aerosol profile information and the quality of water vapor profile inversion.

IMPACT/APPLICATIONS

Advances in this work impact several fields in addition to that of naval sensor performance modeling: linear inversion theory (via advances in mathematics and methods), air-sea interaction (by providing new probing methods and information for near-surface fluxes), and boundary-layer meteorology (by improving understanding of lower boundary conditions and radiative and latent heat fluxes). Moreover, the general method of using scattering near an absorption feature to profile concentration of the absorber may be applicable to other atmospheric trace gases, in particular methane and chloroflurocarbons, which have strong absorption features at infrared wavelengths.

TRANSITIONS

Transitions from this work to related efforts have not yet been made.

RELATED PROJECTS

Water vapor estimation methods developed in this work may be adapted to related problems, including those involving other trace gases, in other geophysical settings.

SUMMARY

We have developed the underlying theory for a new means of sensing trace gas concentrations in the atmosphere. In particular, this method may be a practical means (in a field otherwise lacking any such means) to estimate the vertical profile of water vapor at low altitudes over the ocean surface. Our work thus far has focused on what mathematical inverse theory can tell us about the prospective strengths and weaknesses of the new method – the next step is then obviously experimental testing, though this is difficult using only data that already exist. Thus we expect the next logical step in this effort to be planning to acquire and analyze observations to test, and possibly refine, the theory for eventual use in operational remote sensing.. This project has helped to expand the range of work on near-sea-surface atmospheric remote sensing at the Applied Physics Laboratory – University of Washington.

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PUBLICATIONS

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Winebrenner, D.P., and J. Sylvester, "Estimation of vertical profiles of tropospheric water vapor over the sea surface using high spectral resolution observations of sunlight scattered by aerosols I. Using a

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PATENTS

None.